Space, The Final Frontier, JDEM

Galaxy formation: finding ridiculously high-redshift galaxies; and doing it right.

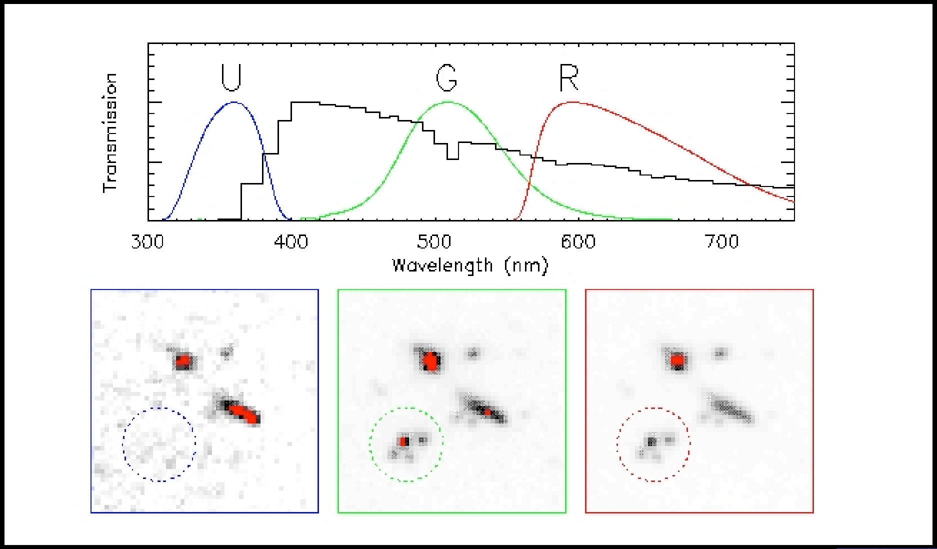
What is in it for Joan/Joe the Astronomer?

What is it going to cost?

Why Reionization?

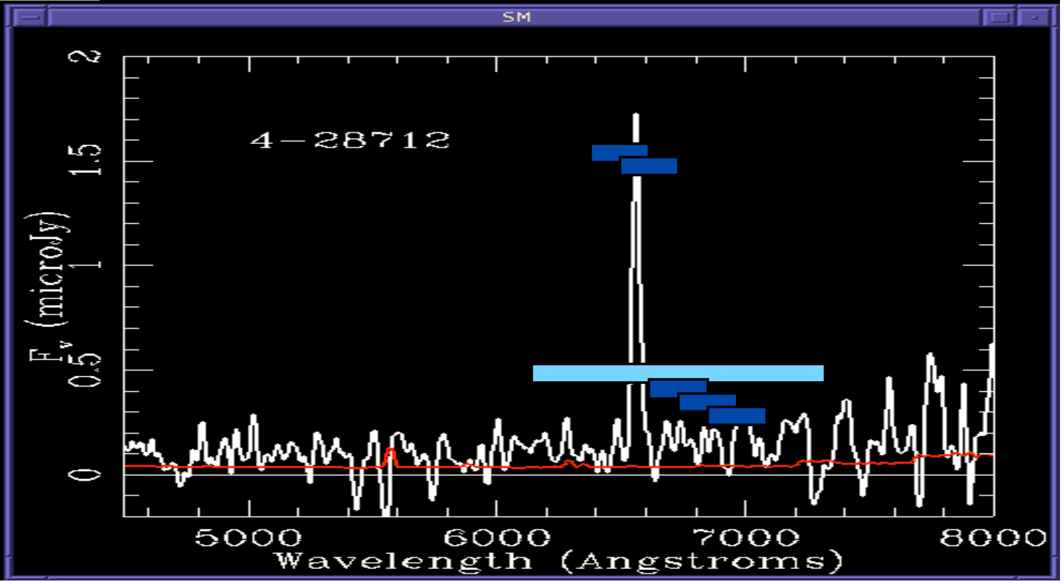
- Reionization sources:
  - Stars in galaxies - likely
  - First stars - possible
  - AGN- currently disfavored
- *Account for UV photons via a census of star-forming galaxies*
- *Use Lyman-alpha galaxies as a test of the ionization state of the IGM*

11 methods of identifying High redshift galaxies

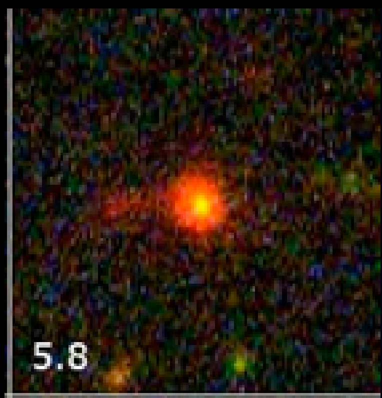


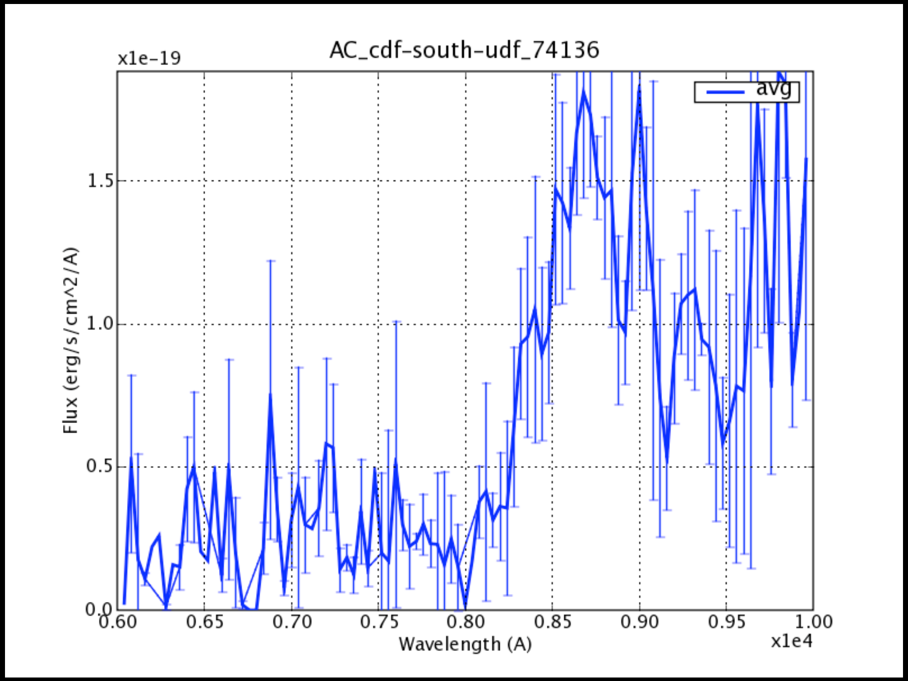
Lyman-break galaxies

Lyman-α galaxies



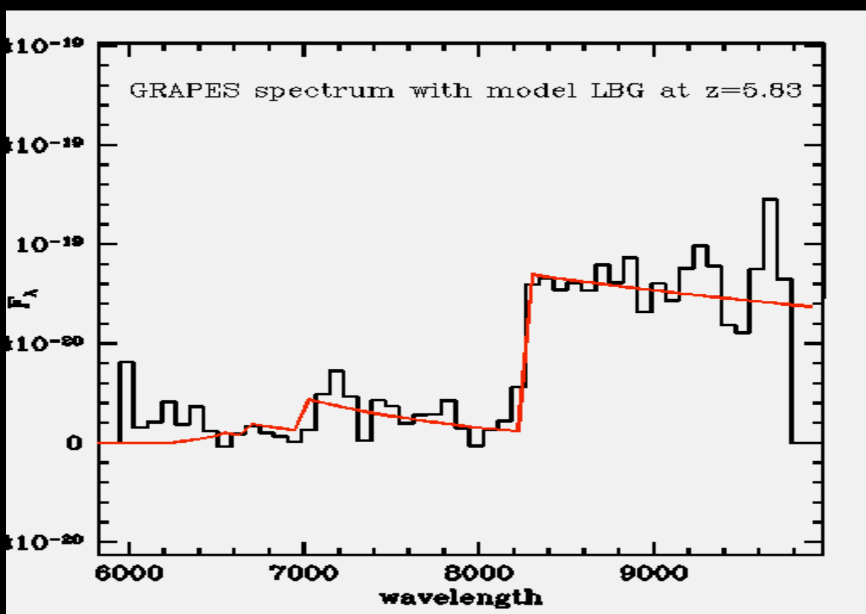
Slitless spectroscopy

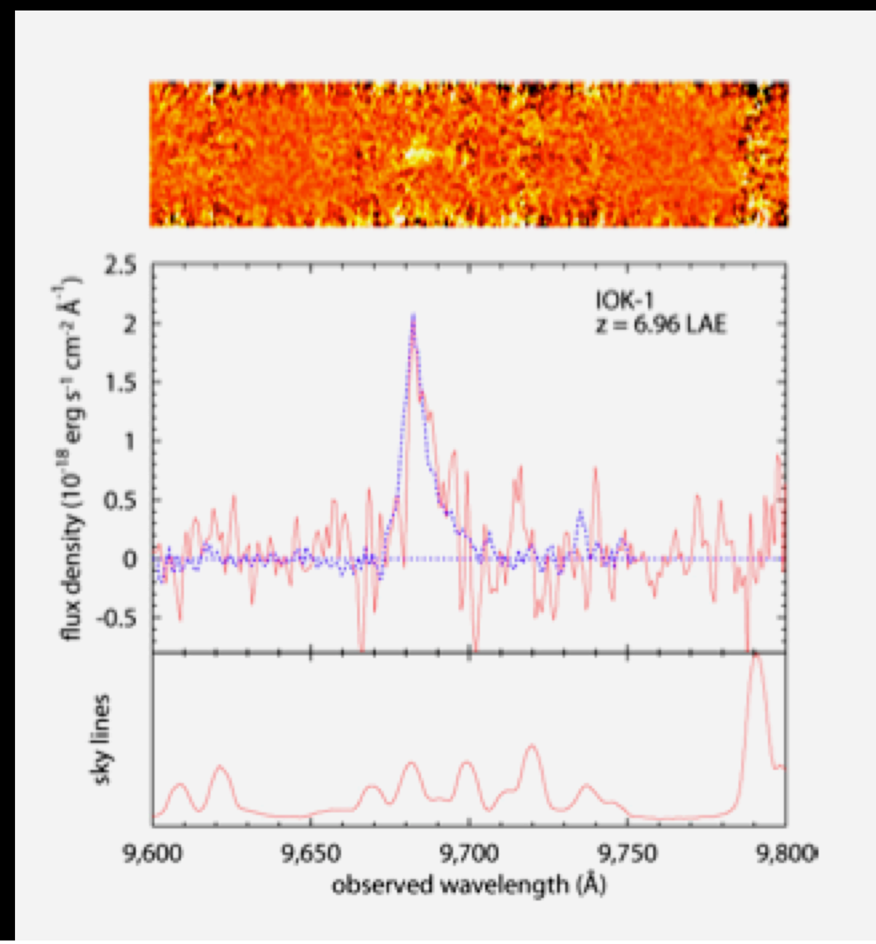




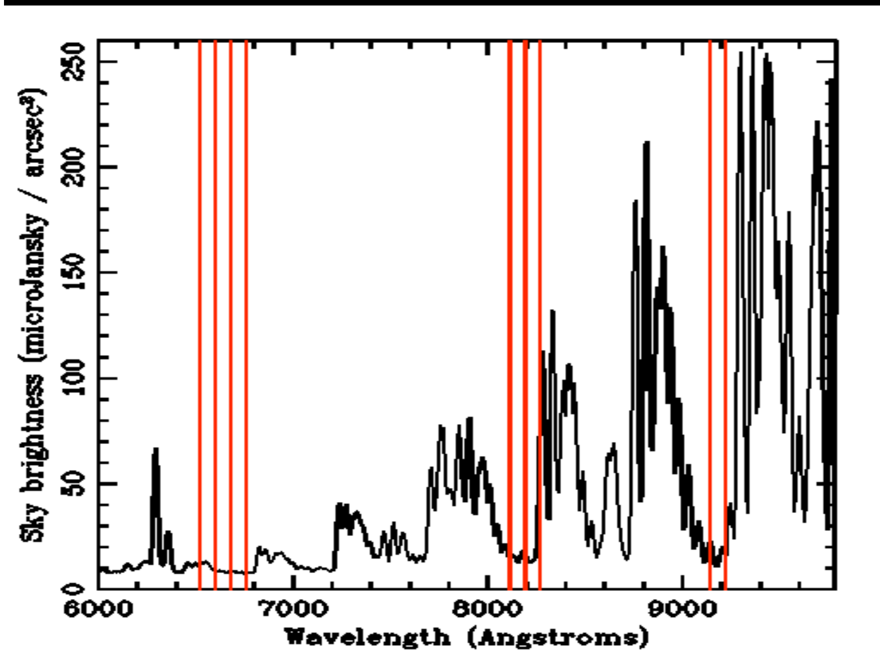
To see galaxies in the Era of reionization, we need to

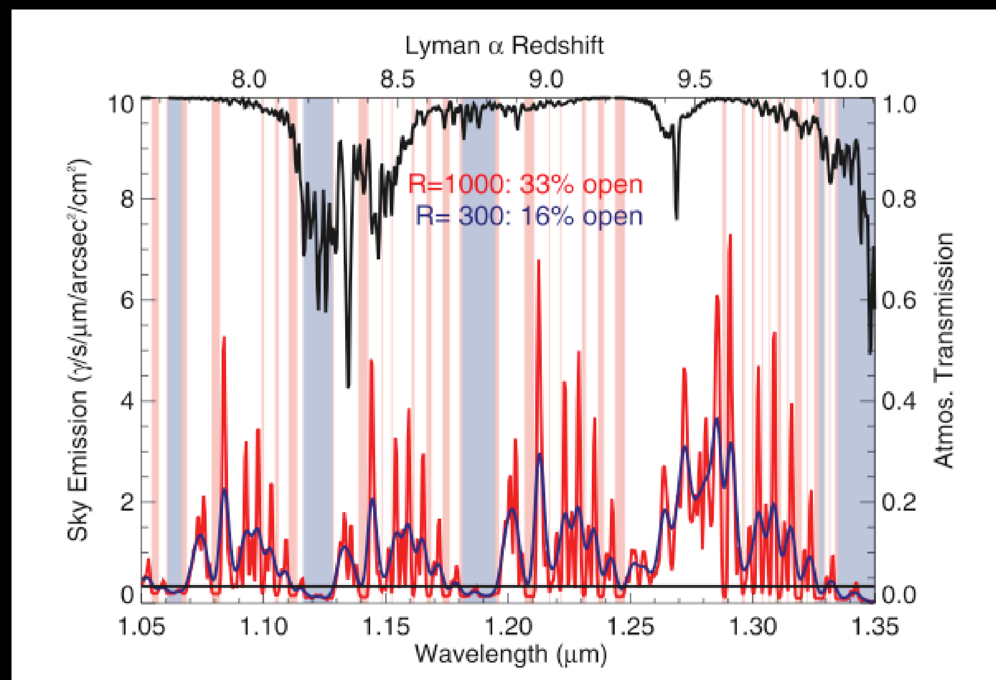
1. Go to the infra red.



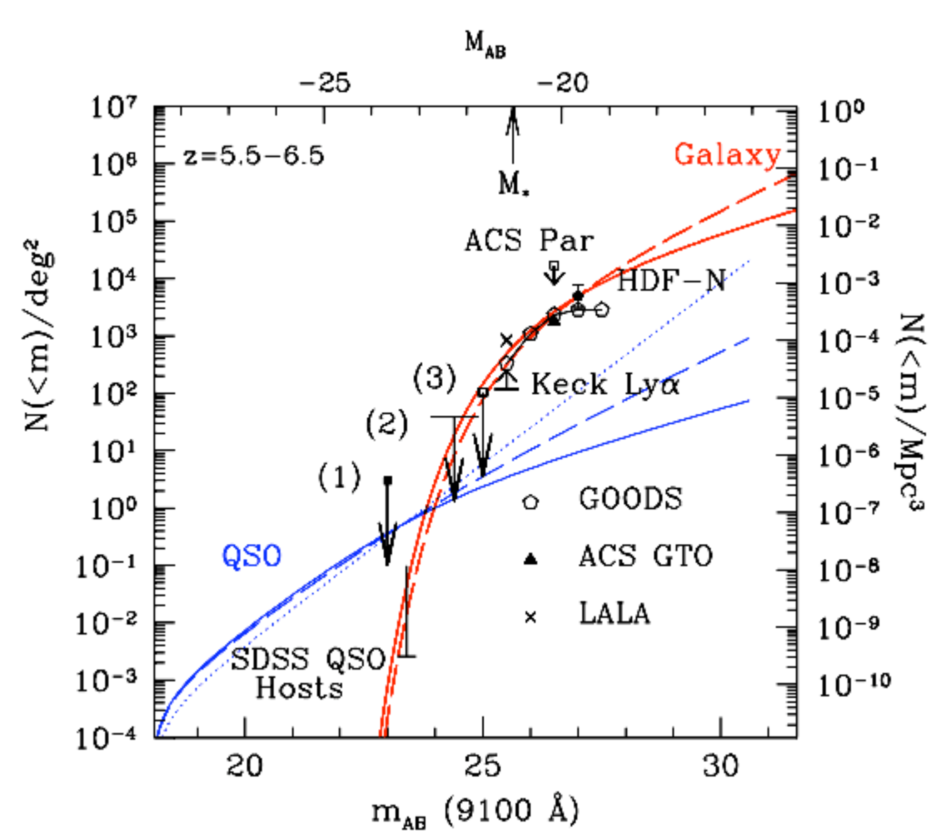


OH forest from the ground

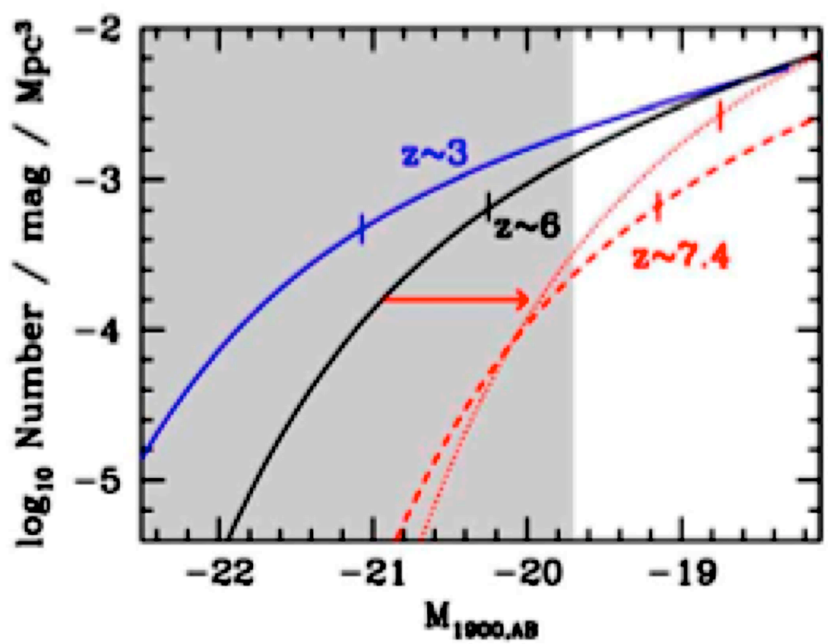




2. Go faint

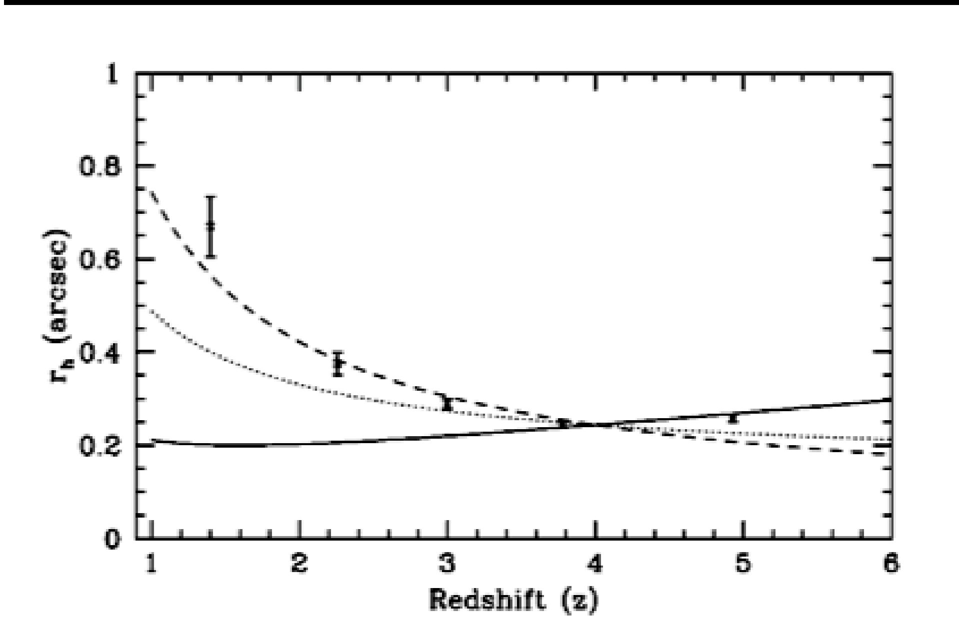


z=5.5−6.5
Galaxy
ACS Par
HDF−N
Keck Lyα
(1)
(2)
(3)
GOODS
ACS GTO
LALA
QSO
SDSS QSO Hosts
N(<m)/deg²
N(<m)/Mpc³
M_AB
M*
m_AB (9100 Å)



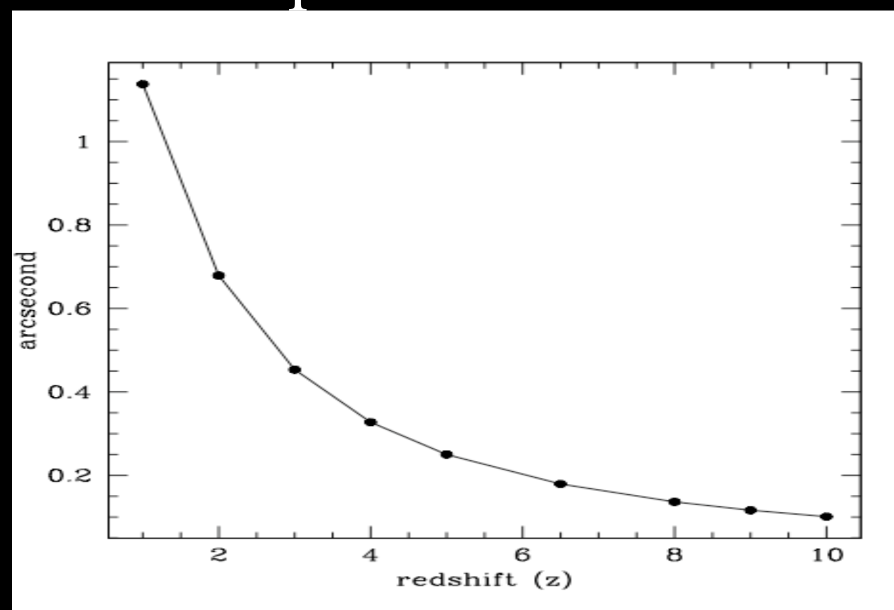
z~3
z~6
z~7.4
log10 Number / mag / Mpc³
M1900,AB

3. Have high spatial resolution



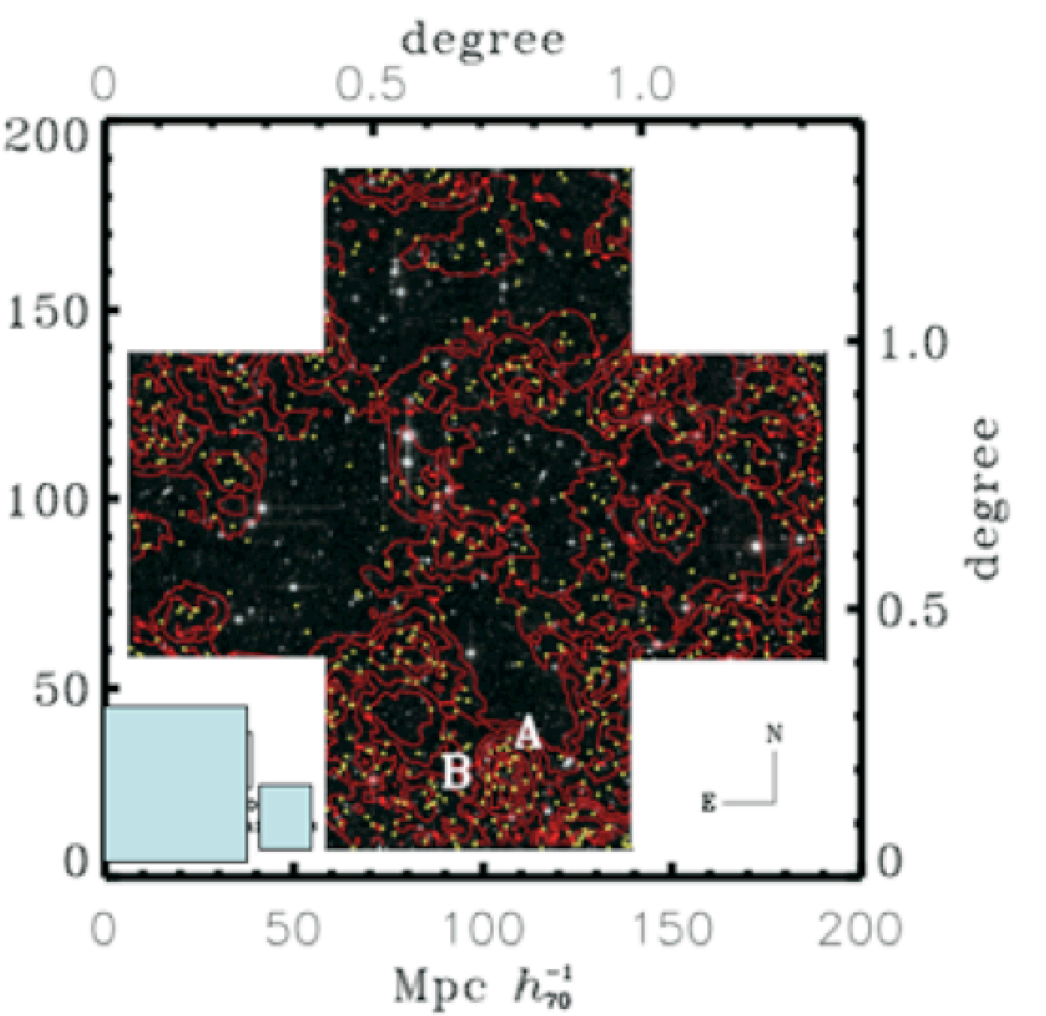
Ferguson et al. 2004

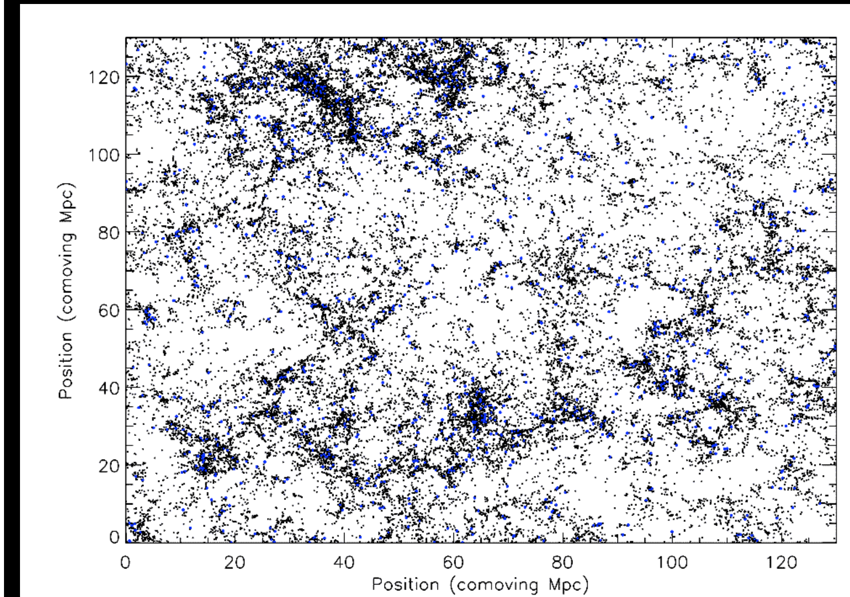
Extrapolation to z~10



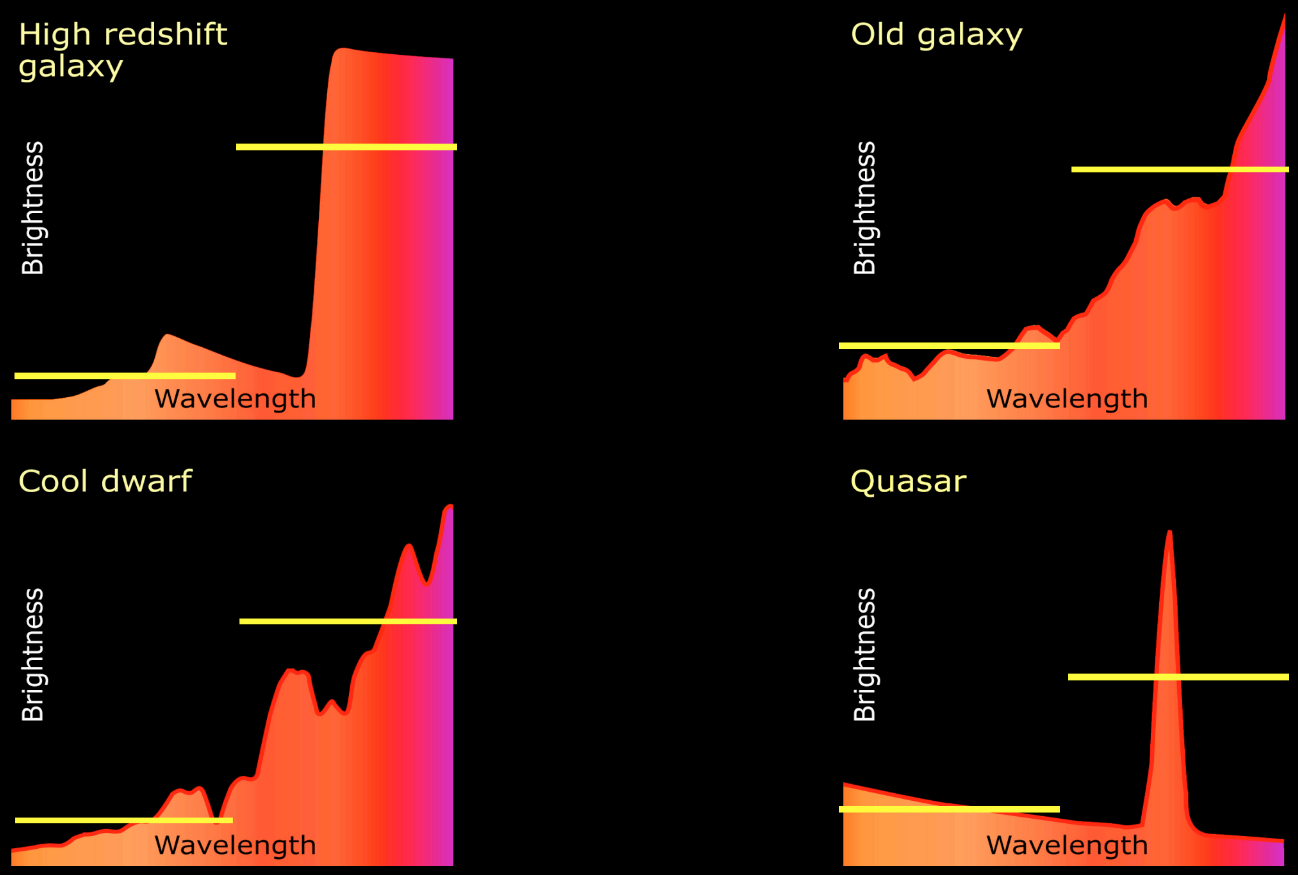
4. Have wide-field surveys

Ouchi et al 05; LSS at z = 5.7, Tilvi et al. 2008

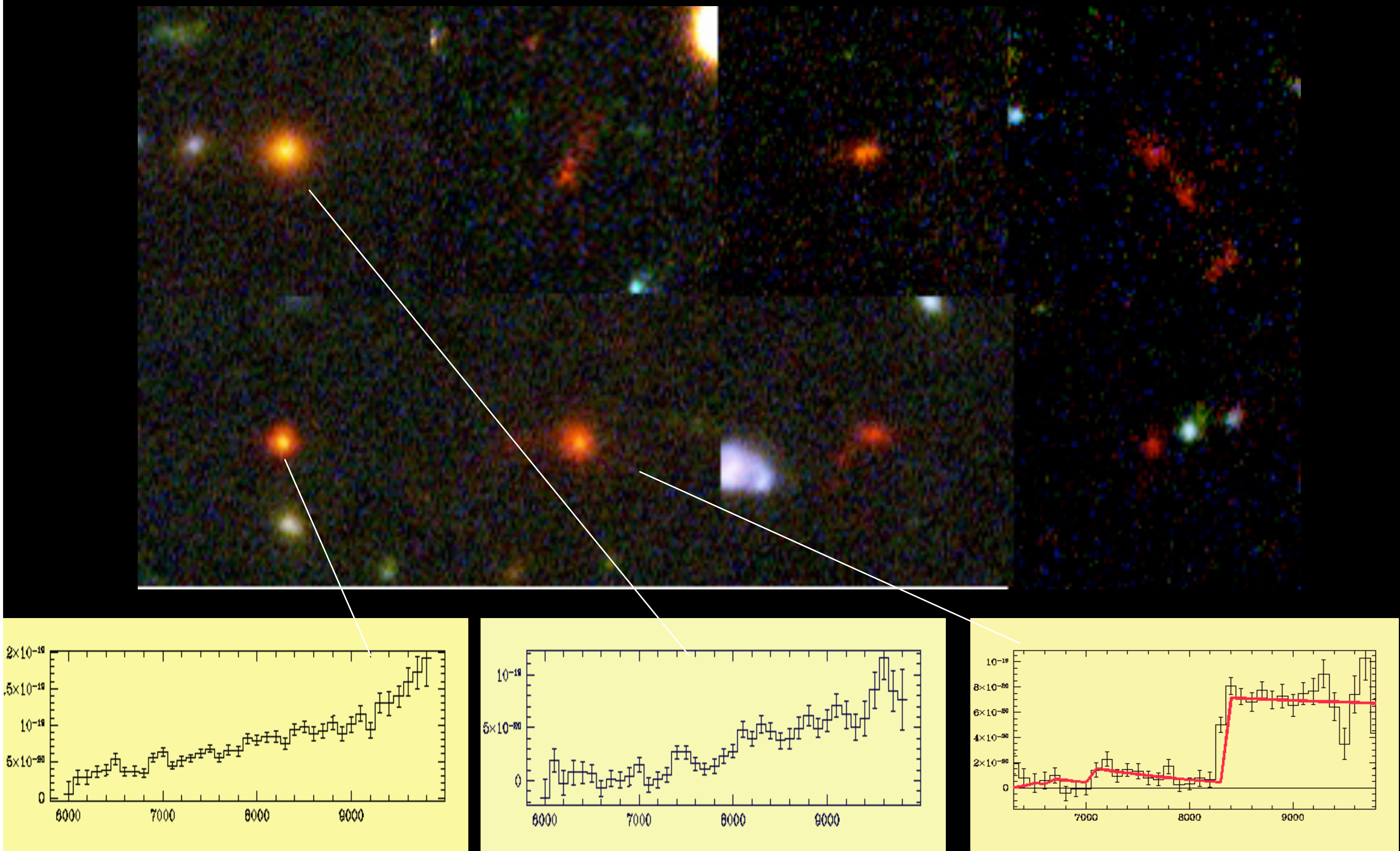




5. Get Spectra to get rid of foreground objects



Which of these are not like the others?

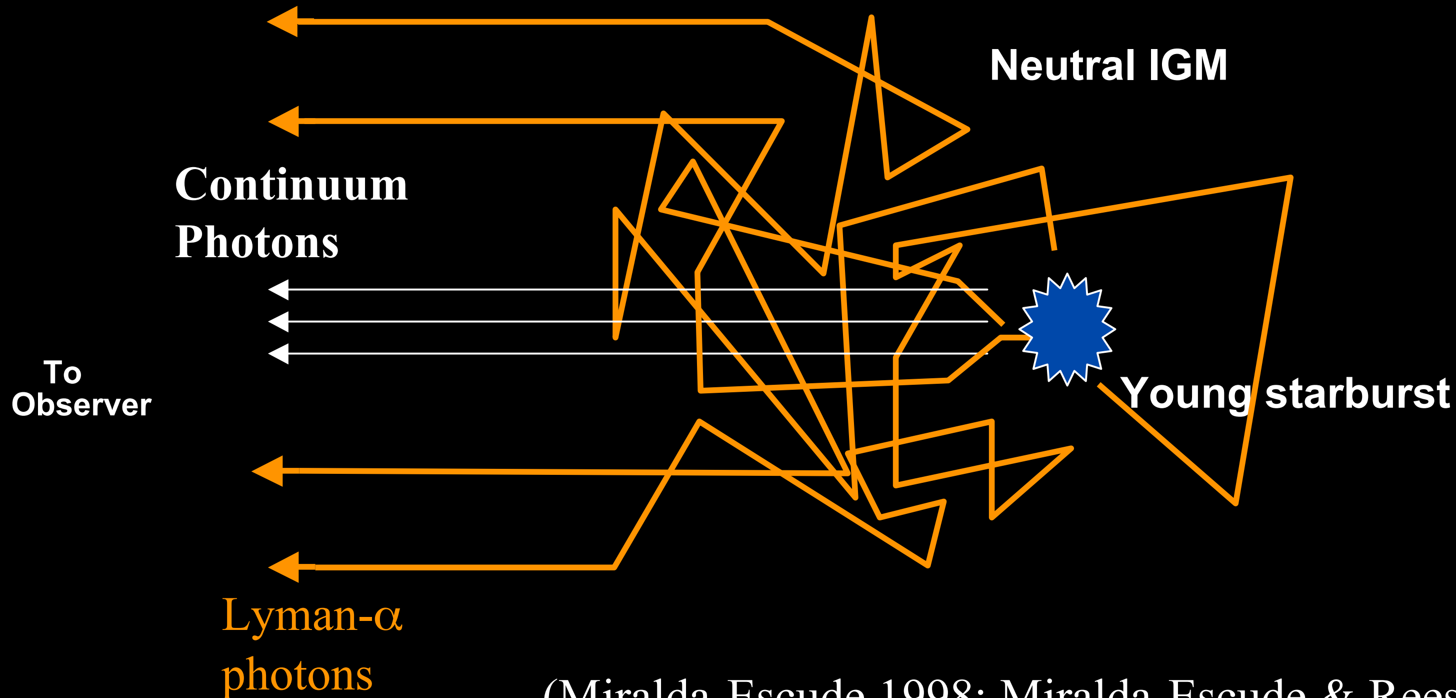


Now that we have good luminosity functions and budgets of UV photons:

Let us probe when and how fast reionization happened

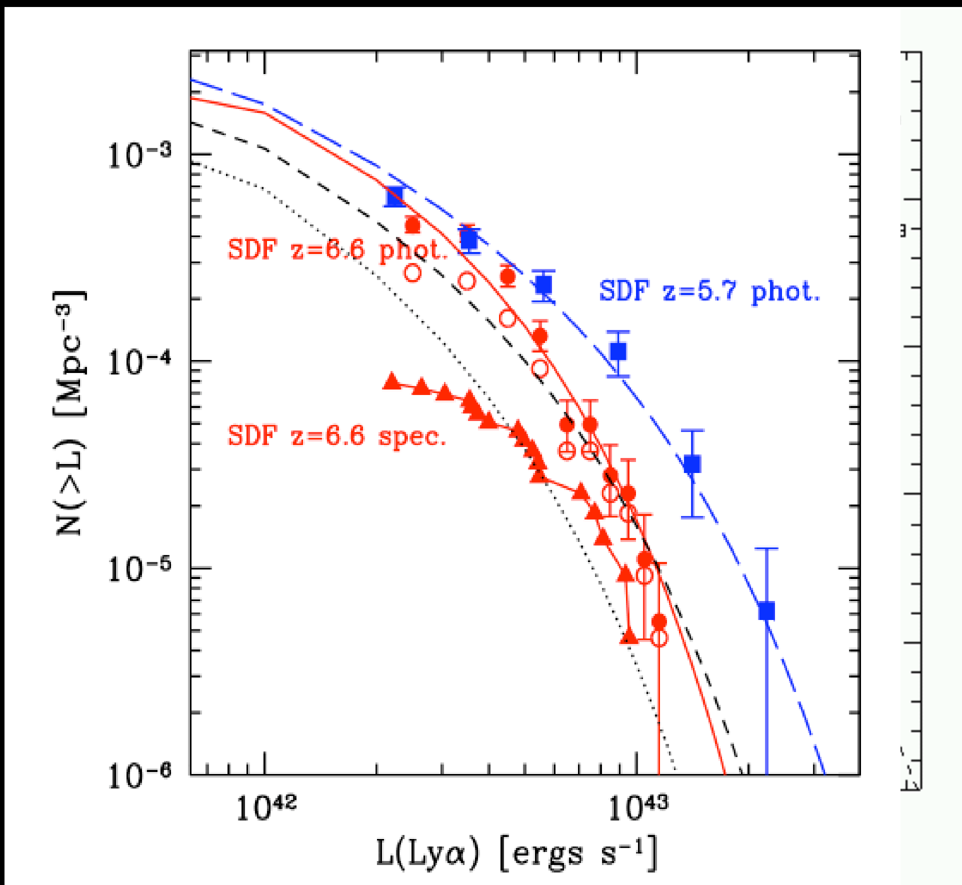
The Lyman-alpha test

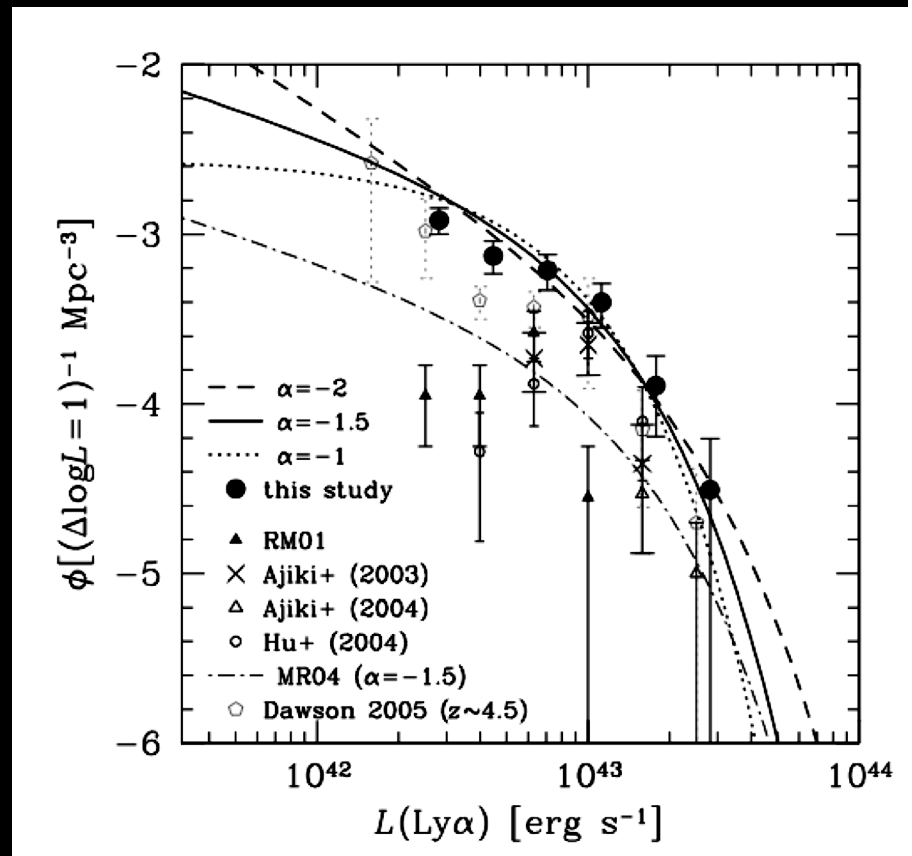
The Lyman-α Test



(Miralda-Escude 1998; Miralda-Escude & Rees 1998;
Haiman & Spaans 1999; Loeb & Rybicki 1999)

Ly-α Luminosity Function: (Malhotra & Rhoads 2004)





The z=5.7 LF from Shimasaku et al is the highest yet observed.

If we compared z=6.5 from K06 to any other z=5.7 LF, the difference would be smaller... Field to field variations?

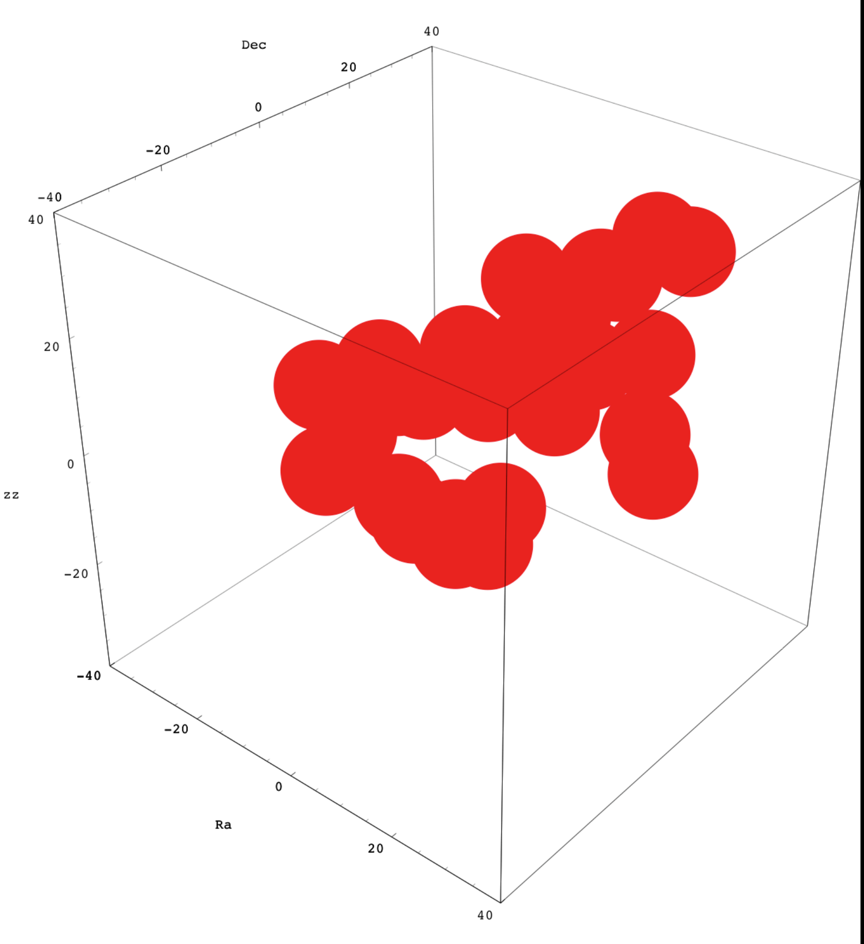
The volume test:

(Malhotra & Rhoads, 2006)

Suppose each Lyman-α emitter is visible because of a local Stromgren sphere, created by neighboring undetected dwarf galaxies, hidden AGNs, decaying dark matter, tooth fairies …

- We know the space density of Lyman-α galaxies at z=6.5

  $\rho > 1\text{x}10^{-4}$ $cMpc^{-3}$ (Taniguchi et al. 2005)
- Place each one in a ionized bubble of the smallest size to enable escape of half of the line flux in an otherwise neutral medium
  - $[V(I)] > 4\pi/3(R_{ss}Mpc)^3$
- Get a filling factor: f = n V ~ 30%

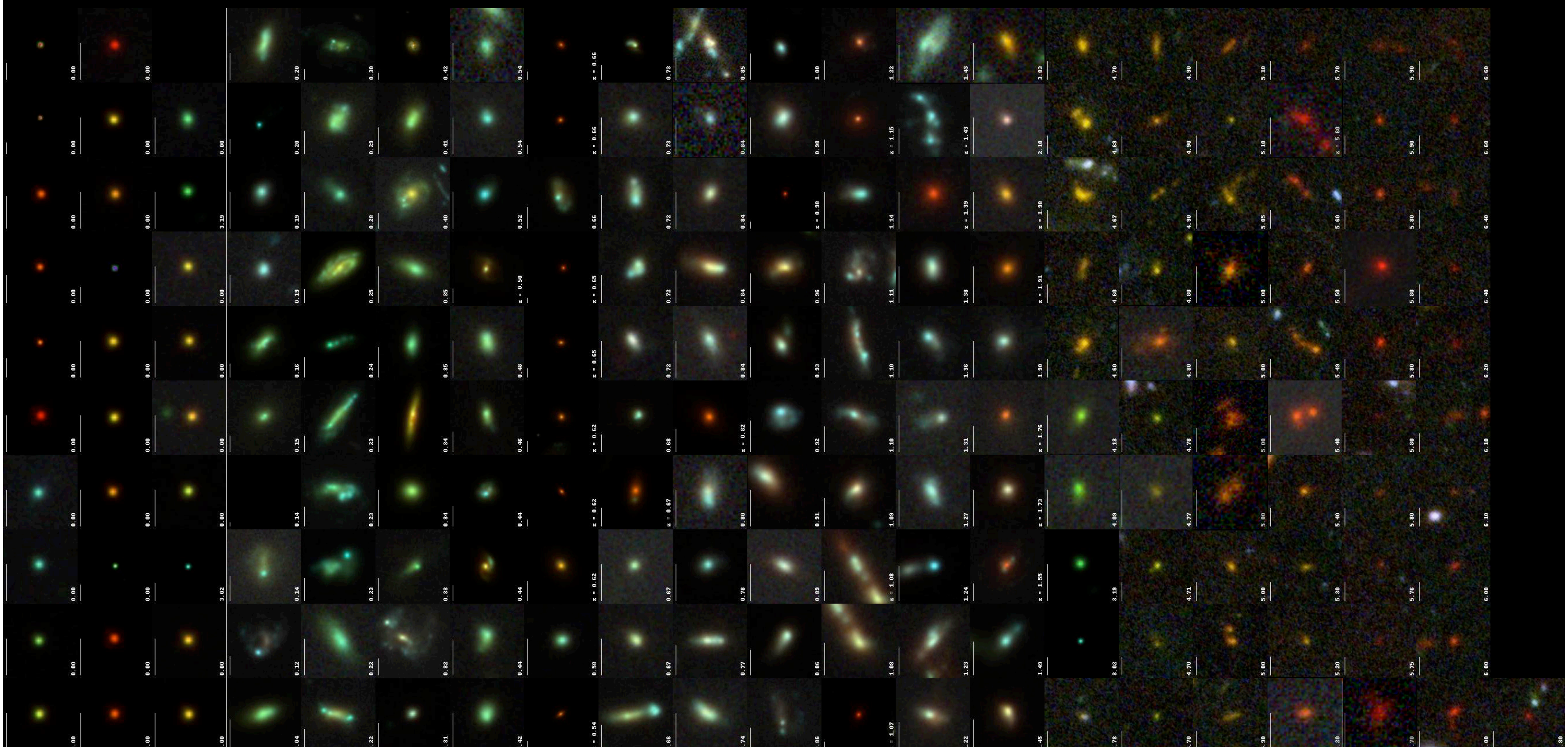


Redshifts from low-resolution spectra:

1. M/L/T dwarfs
2. White dwarfs
3. Strong Emission line galaxies
4. Ellipticals/Bulges: strong 4000 A break
5. Lyman break galaxies
6. AGNs: type I as well as type II
7. Lyman-alpha galaxies
8. SNe I

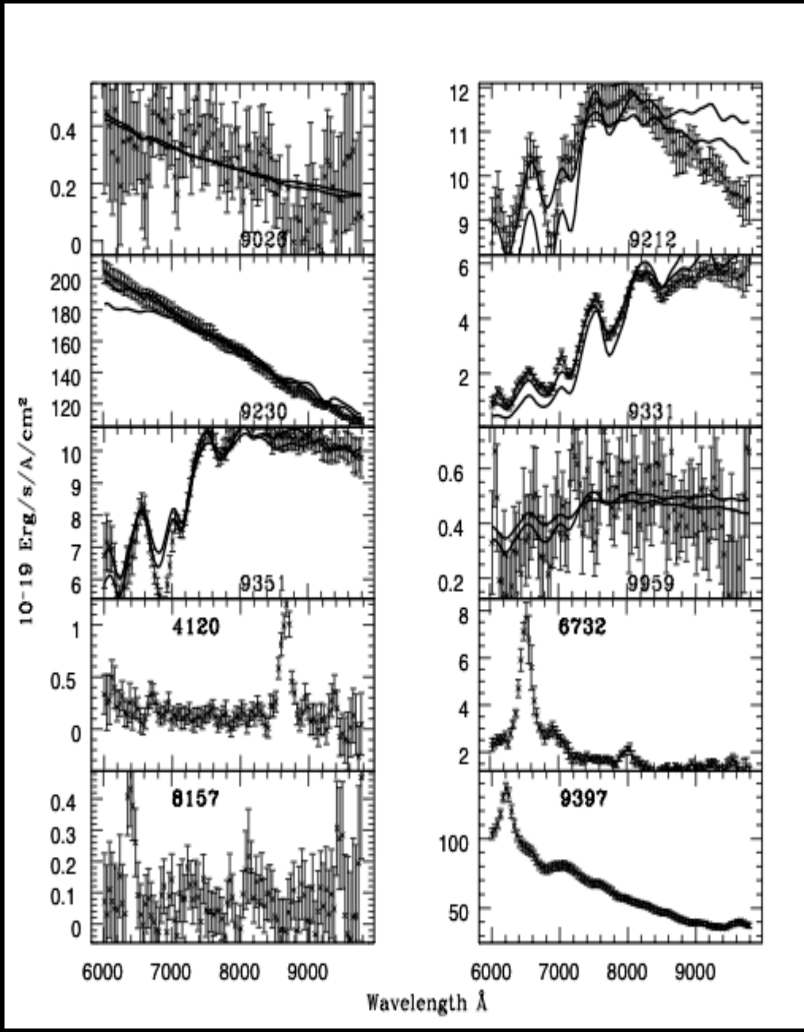
Spectroscopically identified objects:

from 600 to $6.7\text{x}10^{10}$ pc



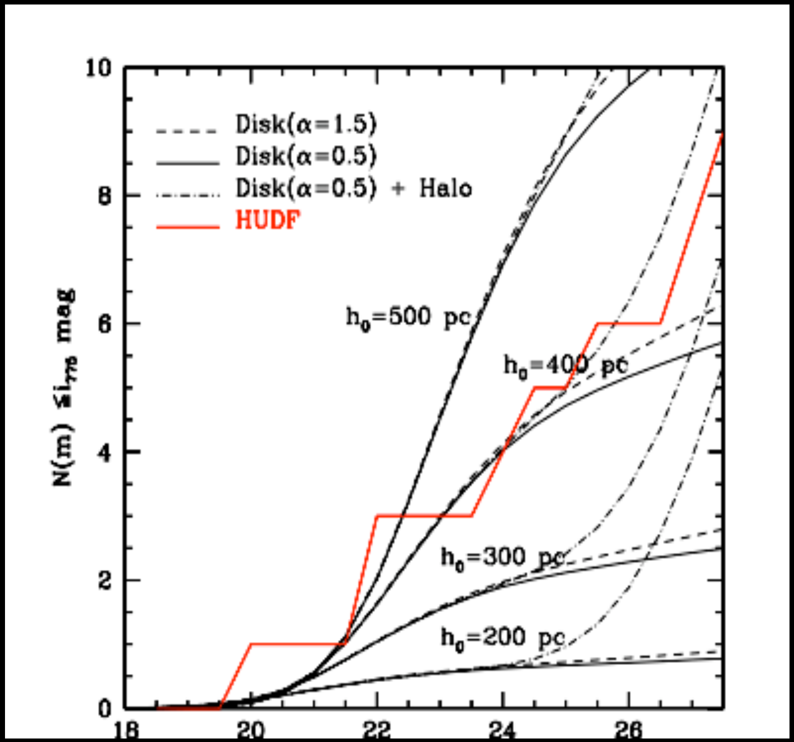
Point sources in the HUDF

Pirzkal et al. 2005



- 46 point sources identified on the basis of morphology to z'=29.5 magnitude.
- Spectral identification to z'=27-27.5 magnitudes
- Include quasars(4), M and L dwarfs, white dwarfs

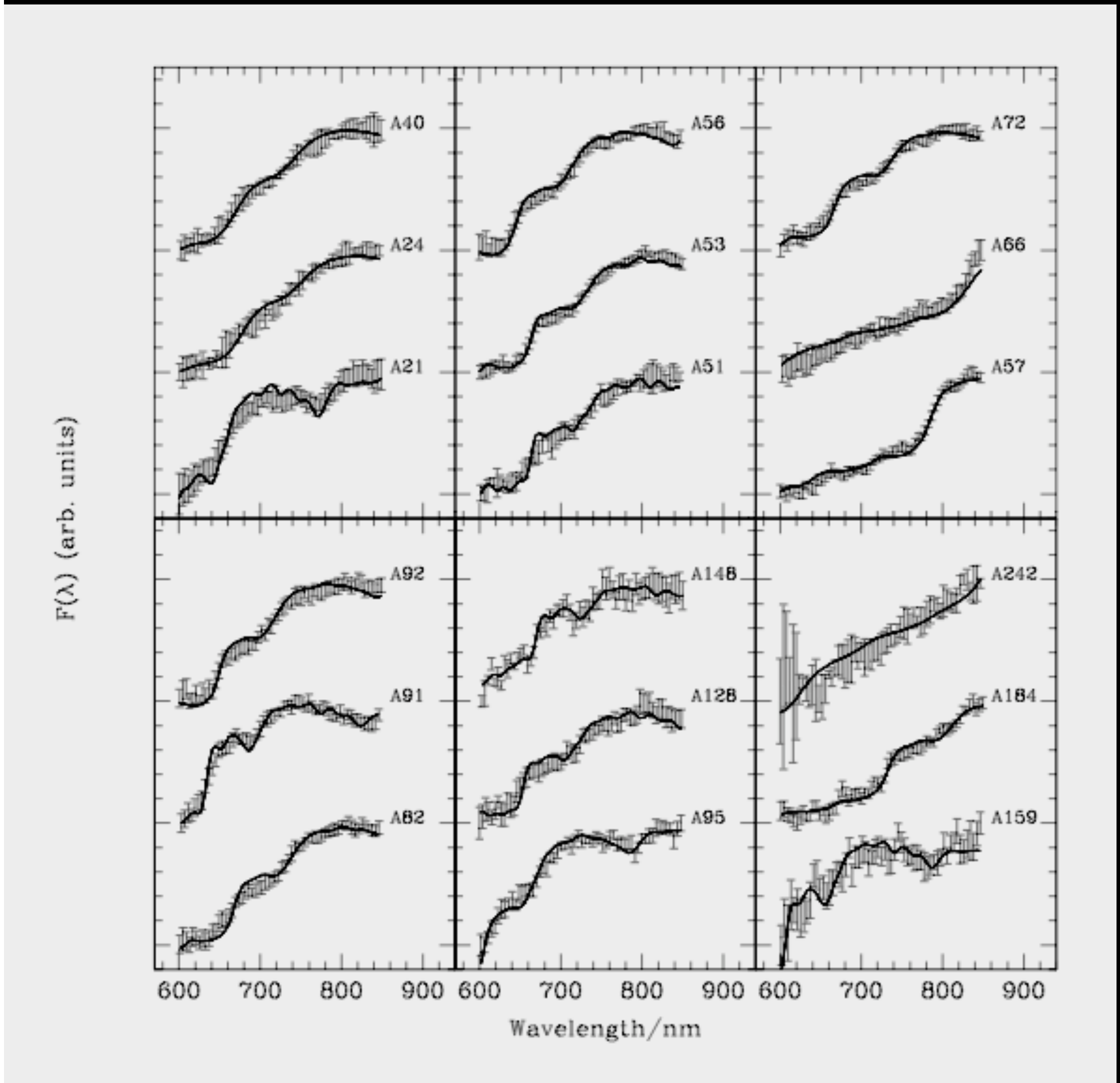
Galactic structure (Pirzkal et al. 2005, 2008)



- White dwarfs < 10% of the Dark Matter halo of our Galaxy

- M-dwarfs to constrain the scale height of old disk: 400 +/- 35 pc.

Ellipticals at z~1 (Pasquali, Ferreras et al. 2005)

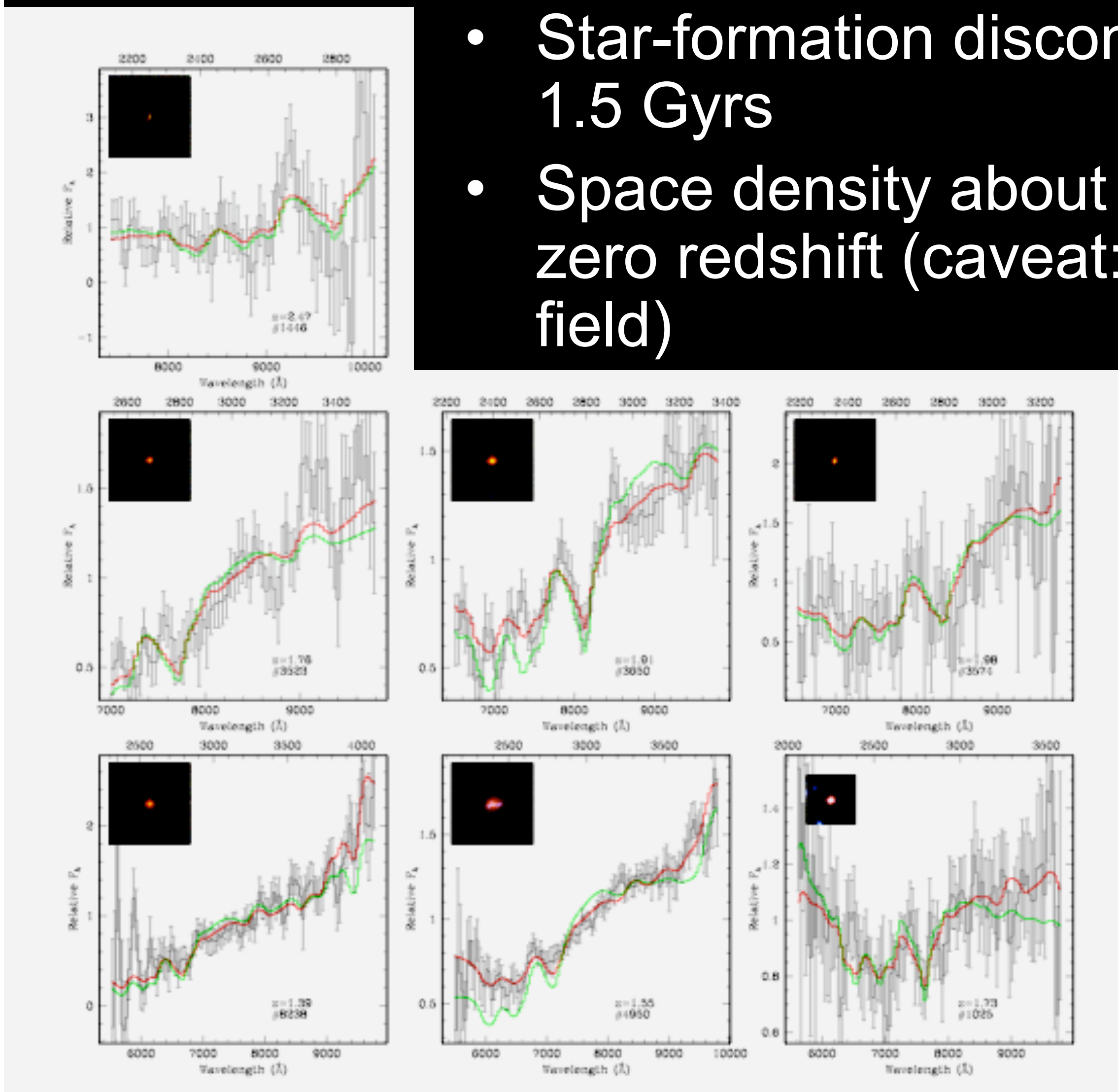


Old stellar populations (3 to 6 Gyrs)

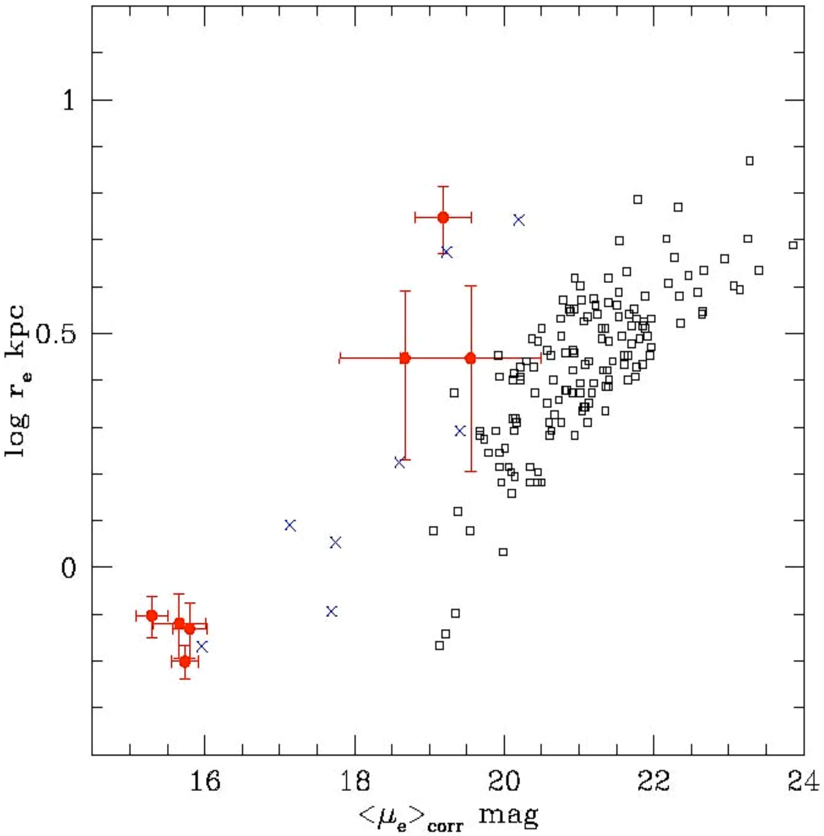
formation redshifts larger than 2

Ellipticals at z=1.4-2.5 (Daddi et al. 2005)

- 10^{11} solar masses, and ages of >1.5 Gyr.
- Star-formation discontinued over the last 0.5-1.5 Gyrs
- Space density about 2-3 times lower than at zero redshift (caveat: one small (3'x3') ACS field)

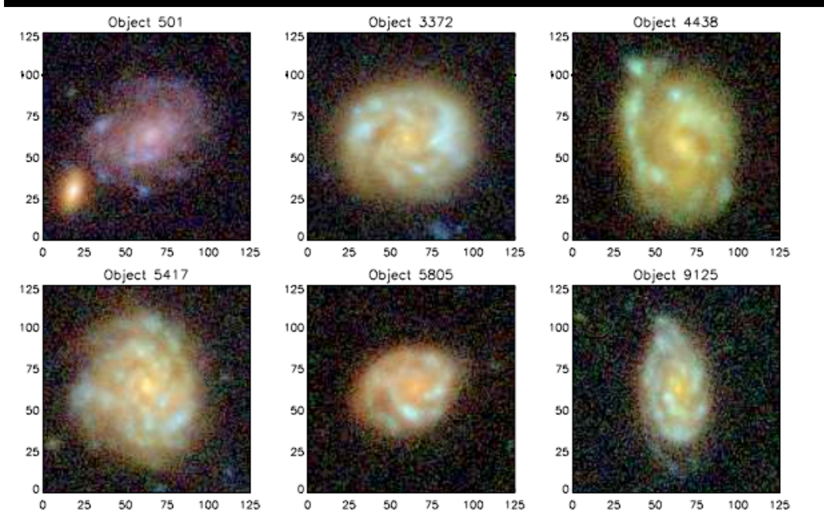


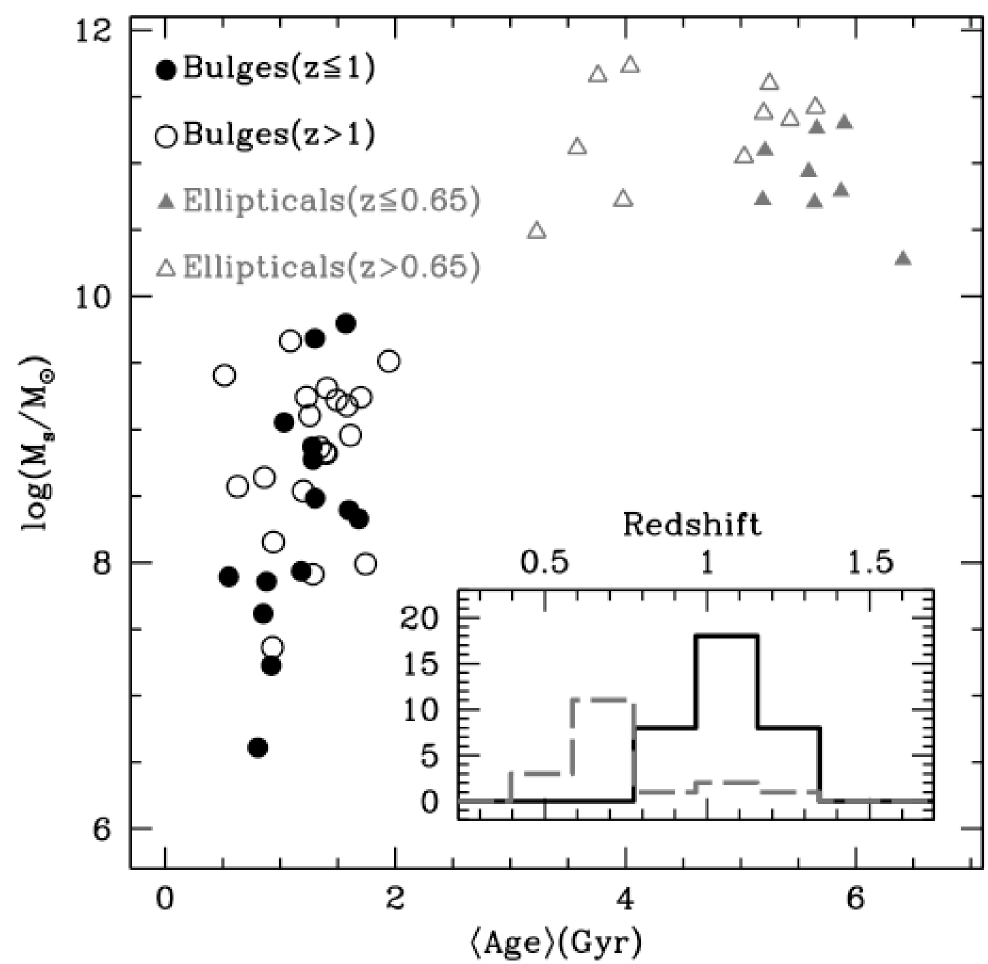
Sizes of z~2 early type galaxies (Daddi et al 2005).



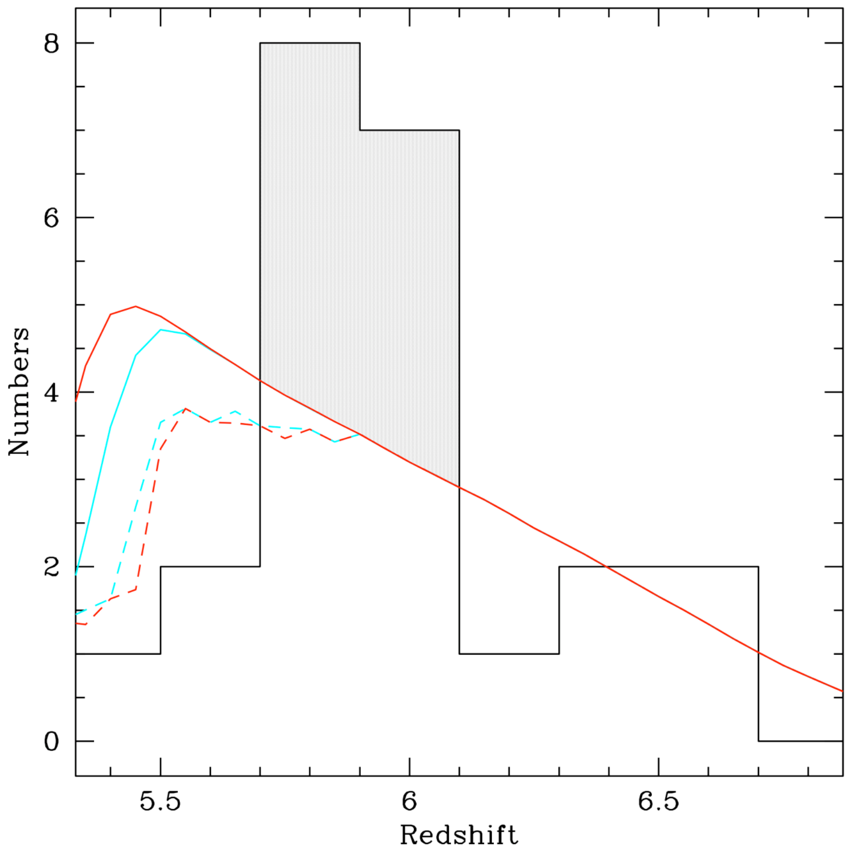
- Small sizes of the z~2 ETGs
- Passive evolution to z~0 will bring them down to the Kormendy relation for Coma.
- Surface mass density 10x ellipticals at z~0 with similar masses, so cannot be progenitors of z~0 small ellipticals, have to 'grow' their radii.

Bulges at z~1: (Hathi, Ferreras, Pasquali et al. 2008)





A spike in the Redshift distribution (Malhotra et al. 2005)



Comparison of observed redshift distribution (histogram) vs. expected numbers

The spike at z~6 is at least a factor of two over-dense.

Salient results from GRAPES

PEARS

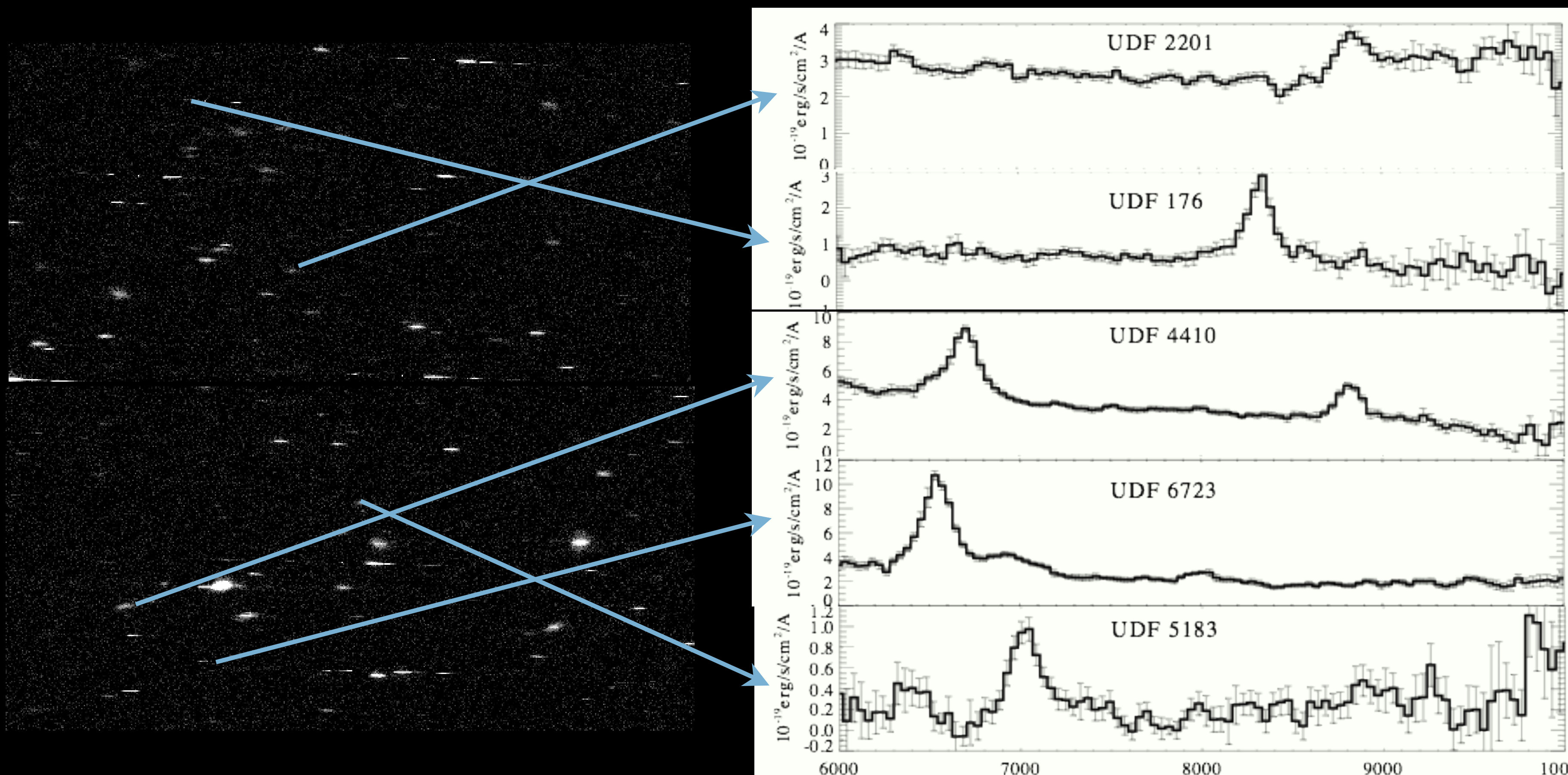
1. Too few white dwarfs: < 10% of the DM halo (Pirzkal et al. 2004b)
2. Scale Height of M-dwarfs in the Galactic disk.
3. Ellipticals at z~1 much like z~0 (Pasquali et al. 2005)
4. Too many Ellipticals at z~2 more compact: (Daddi et al. 2005)
5. Unusually difficult data set to reduce (Pirzkal et al. 2004a)
6. Catalog of line emitters at z~1 (Xu et al. 2007)
7. Luminosity function of [OII] emitters at z~1 (Pirzkal et al. in prep)
8. Line emitters are small, high surface brightness objects (Pirzkal et al. 2005)
9. Formation epoch of z~1 Ellipticals: Ferreras et al. 2009
10. Better spectro-photo-z's: Ryan et al. 2007
11. Emission line galaxies: Straughn et al. 2008.
12. Old populations in late type bulges at z~1 (Hathi et al. 2008)
14. Improved Photometric Redshifts with Surface Brightness Priors (Xia et al. 2008)
15. Five thousand redshifts from PEARS (Cohen et al. 2009)
16. Type-II AGNS in the GOODS field (Grogin et al. 2009)

High redshift science:

17 Unusually large/interacting object at z=5.5 (Rhoads et al. 2004)
18 Large scale clustering at z~6 (Malhotra et al. 2005)
19 Lya galaxies are young and low-mass: (Pirzkal et al. 2007)
20 Luminosity function and Lyman-alpha fraction of z~5 galaxies (Rhoads et al. 2008)
21 Starburst Intensity Limit of Galaxies at z~=5-6 (Hathi et al. 2008)

GRAPES sample

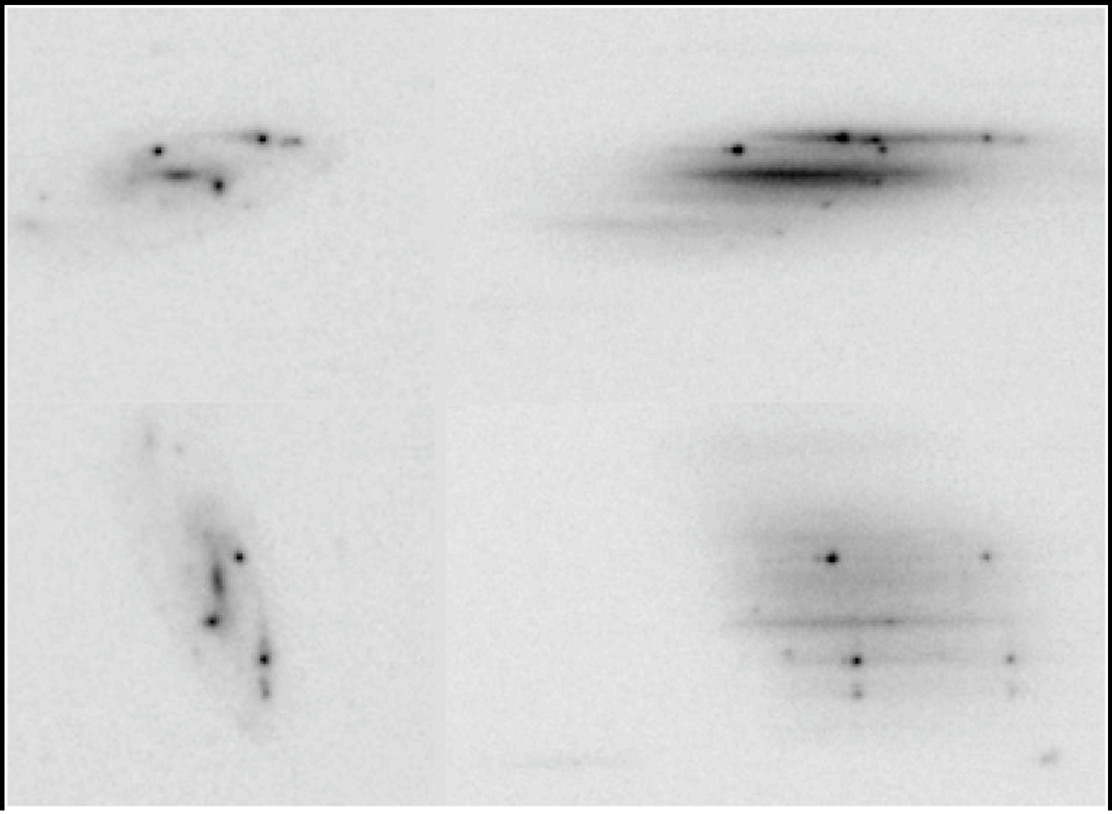
(A nice science free slide)



If only slitless extraction was that easy...

Complications

- Each pixel has all of the sky and about 1/100th of the object flux.
- 3-D flat field; sky is a different color.
- High chance of overlap of spectra.



Products from a SNe/BAO survey

- Try wide-field slitless spectroscopy in the NIR
  - 28th mags AB over 10 square-degrees
    - 500,000 LBGs at $5 < z < 12$
    - 150,000 Lya emitters
    - AGNs at high redshift
    - Old stellar populations at $z > 1.5$: 25,000 Ellipticals
    - Galaxies Clusters at high redshifts
    - Ha, [OII],[OIII] at high redshifts ~ a few million.
    - M, L and T dwarfs: Galactic structure

Tradeoffs between pixel size, resolution, Volume, sensitivity